FINAL REPORT

Cumulative and Synergistic Effects of Physical, Biological, and Acoustic Signals on Marine Mammal Habitat Use

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LONG-TERM GOALS

The long-term goal of this research effort was to enhance the understanding of how variability in physical, biological, and acoustic signals impact marine mammal prey and resulting marine mammal habitat use. This is especially critical in areas like the Bering Sea where global climate change can lead to rapid changes of the entire ecosystem. The Arctic is projected to experience “ice-free” summers within 30 years (Wang & Overland, 2009). This will have significant impacts for the natural ecosystem dynamics and human use associated with transportation, fishing, military activity, and energy exploration. Shifts in plankton community structure are a likely response to large-scale changes in ice cover. Zooplankton population dynamics are a dominant component of the ecosystem that provide the crucial trophic link between primary production and Federally-protected species such as marine mammals. Synoptic measurements of marine mammal vocal presence, prey concentrations, physical oceanographic processes, and sound levels were made to better understand the relationship between environmental sound levels, ice cover and zooplankton community structure in different regions of the Bering Sea. These combined datasets provide information for predicting upper-level trophic dynamics, including marine mammal distribution and range, as sub-Arctic conditions continue to change. Baseline measurements are playing an important role in mitigation efforts and environmental assessments as commercial, recreation, and military activity increase in the region.

OBJECTIVES

The original proposal objectives focused only on cetaceans. The scope of the project was broadened to include pinnipeds during the first year as a result of preliminary analyses of the passive acoustic dataset; thus, cetacean was changed to marine mammal in all objectives.

1. *To determine the temporal variability in sound level and sources in the southern and central areas of the Middle Shelf domain in the Bering Sea*
2. *To investigate the relationship between physical processes related to wind intensity, storms, and sea ice coverage with zooplankton/fish abundance and marine mammal presence*
3. *To examine the relationship between temporal prey abundance and marine mammal habitat use*
4. *To investigate the combined effect of physical processes, environmental sound and prey availability on marine mammal habitat use.*

Two one-year expansion efforts building upon the original project were granted to more closely examine the details of 1) adaptive sampling algorithms in passive acoustic monitoring with Passive Aquatic Listeners (PALs), and 2) acoustic backscatter beyond simple abundance estimates. These efforts addressed additional objectives that contributed to the successful completion of the original proposal objectives:

Expansion A
1. *To assess the feasibility of accurately detecting cetacean presence from PAL data.*
2. *To determine the accuracy of species classification from PAL detections.*

Expansion B
1. *What effect do changing sea ice dynamics have on zooplankton populations?*
2. *Do zooplankton dynamics under ice correspond to quantifiable marine mammal patterns?*

APPROACH

Originally Proposed Research and Expansion B

This was a collaborative research effort between Jennifer Miksis-Olds (ARL Penn State), Jeffrey Nystuen (APL University of Washington), Susan Parks (Syracuse University), and Phyllis Stabeno (NOAA PMEL). Expertise in zooplankton dynamics was also contributed by Joseph Warren (Stony Brook University) and Jeffrey Napp (NOAA AFSC). The project integrated active and passive acoustic instruments into sub-surface acoustic moorings at two sites on the eastern Bering Sea shelf (M2 and M5) in collaboration with NOAA's Ecosystems and Fisheries-Oceanography Coordinated Investigations (EcoFOCI) Program (Stabeno et al., 2010) (Figure 1). An additional oceanographic mooring was deployed at each site and was located less than one kilometer from the acoustic mooring. Data collected by instruments on the oceanographic moorings included temperature (miniature temperature recorders, SBE-37 and SBE-39), salinity (SBE-37), nitrate (Satlantic MBARI-ISUS V1), and chlorophyll fluorescence (WET Labs DLSB ECO Fluorometer). Temperature sensors were located at 21, 25, 33, 38, 45, 50, 60, and 67 m. Salinity sensors made measurements at 19, 30, and 55m, fluorescence was measured at 20m, and nitrate was measured at 30m. Data collection began in 2008 under this award and continues to the present at both sites through support of an ongoing project sponsored by NASA.

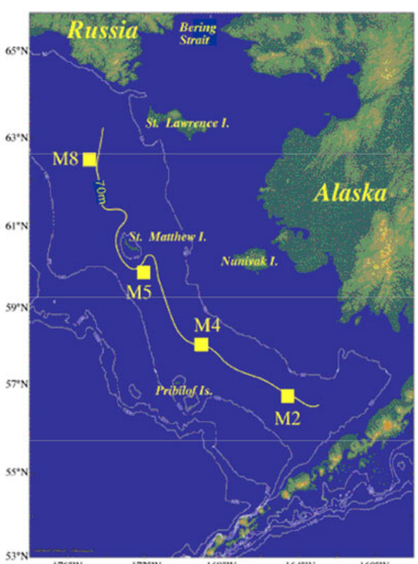

Figure 1. Map of mooring locations along the eastern Bering Sea shelf.

Synoptic measurements of marine mammal vocal presence, prey characteristics, physical oceanographic processes, and sound levels in the Bering Sea were made with a combination of active and passive acoustic technology. An adaptive sub-sampling Passive Aquatic Listening (PAL) recorder and three-frequency echosounder system were integrated into biophysical moorings on the southeastern (site M2) and central (site M5) Bering Sea shelf. The PAL sampled at 2 or 5 min. intervals depending on the sound sources and level of acoustic activity detected in the area. Acoustic activity in this work refers to the occurrence of acoustic events (e.g. animal vocalizations, passing ships, rain, etc.) attributed to identifiable sources, as opposed to the combination of distant sounds that creates the background sound level. The default sampling strategy was to record a 4.5 s time series, or soundbite, at 100 kHz every 5 min. This corresponded to a 1.5% duty cycle. When real-time processing algorithms detected a transient sound or signal of interest in the soundbite, the interval between samples was decreased to 2 min., resulting in a duty cycle of 4% during periods of high acoustic activity. The sampling period of 4.5 sec remained the same. A transient sound is defined in this context as a sound lasting less than the length of a single soundbite (4.5 s). When operating in default (or low duty cycle mode), the average spectrum calculated from each soundbite was saved, and the raw time series was discarded. Data saved during the high duty cycle mode included the raw times series and individual power spectra. The soundbites were used in the post-processing analysis to verify the identity of the sound source triggering the transition from low to high duty cycle sampling. A daily limit of 20 soundbites restricted the number of soundbites saved each day to ensure adequate data storage over each 6 month deployment, but spectra were saved every two or five minutes, depending on sampling mode, throughout the duration of the deployment, which provided a quasi-continuous record of the background acoustic environment with a temporal resolution of 2-5 min. Details related to the PAL sub-sampling strategy, detection thresholds, and probability of detection for marine mammals in the Bering Sea is found in Miksis-Olds et al. (2010).

The echosounder system was comprised of three Acoustic Water Column Profilers (AWCPs) (ASL Environmental Sciences, British Columbia) operating at 125 kHz, 200 kHz, and 460 kHz. The AWCP system was mounted at the bottom of the mooring chain in an upward-looking direction 15^{o} off vertical. The vertical offset eliminated interference from flotation and instruments in the mooring line directly above the active acoustic system. AWCPs monitor the presence and location of acoustic scatterers such as zooplankton and fish within the water column (Brierley et al., 2006; Kunze et al., 2006). The transducers of the three different frequencies were positioned in the mooring cage so that the beam patterns were aligned to sample the same parcel of water nearly simultaneously. All three echosounders sampled the water column for 5 min. each half hour. During each 5 min. sampling period, acoustic backscatter measurements were recorded every 2 s with 25 cm range bins from approximately 0.75 m above the transducer face to the water surface.

The passive acoustic data provided a simultaneous time series of marine mammal vocalizations and changing soundscapes (sound levels and spectral shapes) related to surface conditions and regional activities. Acoustic backscatter recorded by the echosounders provided information on prey abundance, community composition, and water column distribution. Information on regional ice cover in the vicinity of the moorings was obtained from the Advanced Microwave Scanning Radiometer EOS (AMSR-E) system flown aboard NASA's Modis Aqua satellite and from the NOAA ice desk at the National Weather Service in Anchorage, Alaska. Interactions between marine mammal presence and all other environmental variables were investigated using Generalized Linear Models and General Additive Mixed Models as appropriate for each objective. Variables included in the models include daily species specific presence, ice cover, ice thickness, volume backscatter, zooplankton/fish community structure, and sound levels.

Expansion A

Daily classifications of marine mammal vocalizations from two passive acoustic monitors with different subsampling parameters, an AURAL-M2 (Multi-Electronique Inc, Quebec) and a PAL, co-located on the M5 mooring were compared. The PAL and AURAL were deployed serially in the mooring line at depths of 65 m and 67 m, respectively. The AURAL subsampled on a pre-set schedule, whereas the PAL sampled via an adaptive protocol. The AURAL was programmed to record semi-continuously for nine minutes every half hour, a 30% duty cycle, at a sampling rate of 8192 kHz.

Detected signals of interest were manually classified in each dataset independently. A method for classifying ribbon (*Histriophoca fasciata*) and bearded seal (*Erignathus barbatus*) vocalizations from sparse spectral time histories of the PAL was developed and included in the performance comparison.

Daily classifications of species specific vocalizations were computed from each system. The daily quota of the PAL recording paradigm did not permit finer temporal comparisons. The classifications were reduced to the presence or absence of a vocalization from each species for each day. Presence or absence was then compared by species by day between the instruments. Daily classifications from the PAL soundbites and spectra clusters were considered equally.

WORK COMPLETED

<u>*Data Collection*</u>

A PAL and three-frequency echosounder system was first deployed at sites M2 and M5 along the 70 m isobath of the eastern Bering Sea shelf under this project award starting in September 2008 (Figures 2 and 3). A year of PAL data was also available from September 2007-September 2008 as part of a separate project (Figure 3). Data collection continues today under a NASA grant that ends in August 2013. Mooring maintenance cruises for sensors at M2 took place in May and late September of each year. Spring ice extent limited access to M5, so maintenance was conducted on an annual basis in late September. The instruments were retrieved during each maintenance cruise, refurbished, and re-deployed on the same day, which limited data gaps to less than 12 hours during the mooring maintenance period. Data gaps larger than 12 hours were due to either instrument malfunctions or the trawling up of the entire mooring by a fishing vessel in Nov 2008 at M2 (Figures 2 and 3).

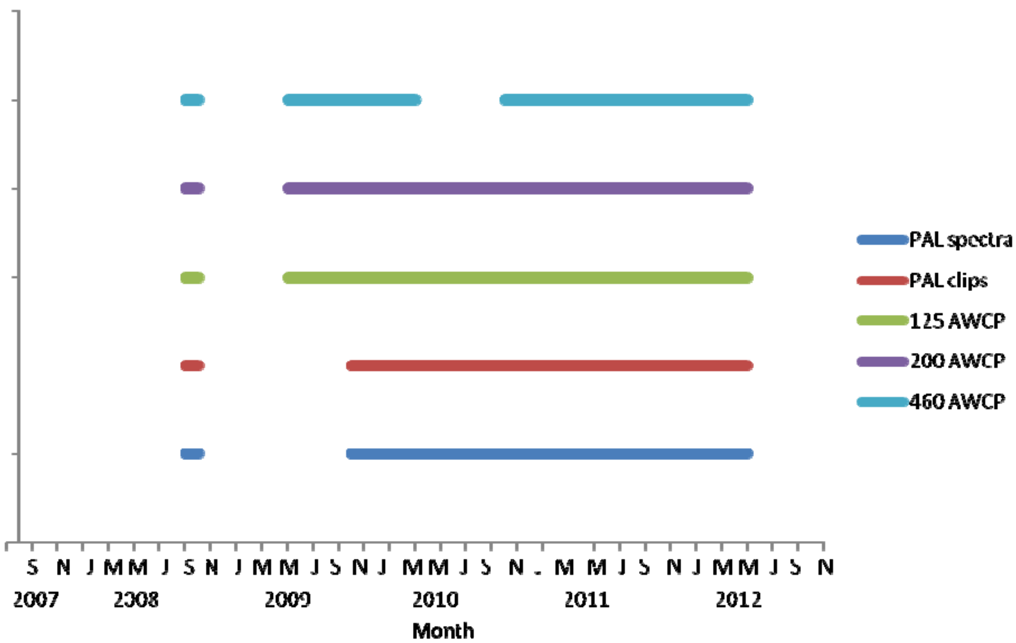

Figure 2. Data acquired under this award and available for analysis from site M2. Sensors are currently deployed at this site with a recovery planned for September 2012.

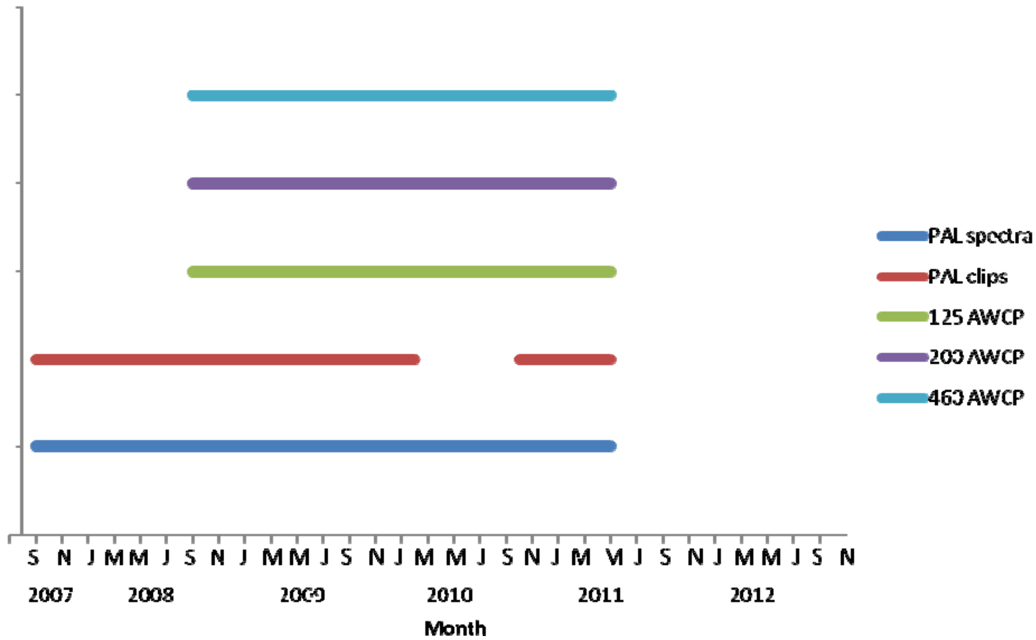

Figure 3. Data currently available for analysis from site M5. Data collection from Sept 2007- Sept 2008 was supported under a separate project. Data from Sept 2008 to the present were acquired under this award. Sensors are currently deployed at this site with a recovery planned for September 2012

<u>*Data Analysis*</u>

Analysis of the passive acoustic dataset recorded by the PAL was divided based on the data type: soundbites and spectra. Soundbites were processed to detect and classify transient signals. Each soundbite was reviewed by a human classifier and verified by a second independent human classifier blind to the results of the first reviewer. Sound sources detected in the soundbites were identified from spectrograms (1024 point FFT, Hamming window, 87.5% overlap) made from the original 100 kHz recordings using Adobe Audition 3.0 (Adobe Systems Incorporated). These settings provided a binwidth of 61 Hz, with a frequency resolution of 47 Hz, and a time resolution of 2.7 ms (Miksis-Olds & Parks, 2011). Biological signals were classified aurally and visually from the spectrograms by species (bowhead whale (*Balaena mysticetus*), humpback whale (*Megaptera novaeangliae*), gray whale (*Eschrichtius robustus*), killer whale (*Orcinus orca*), beluga whale (*Delphinapterus leucas*), walrus (*Odobenus rosmarus*), ribbon seal, and bearded seal).

Analysis of PAL spectra included examination of the number of transient signals detected over time, as well as the spectral content and levels of the spectra. Sea ice produces sound underwater via several different physical mechanisms. These sounds are distinctive and were identified by their spectral content, allowing surface ice conditions to be identified from the time series of PAL spectral data. The PAL spectral data were compiled and temporal clusters of distinctive sound spectra were manually examined and classified. Validation of sea ice conditions from the passive acoustic data was inferred from the satellite ice thickness and mean ice cover calculations, seasonality, and recorded soundbites of physical processes. The number of transient detections was summed over each hour of the acoustic time series.

Performance evaluation of the PAL (Expansion A) was assessed by comparing PAL detections to those of the AURAL. Marine mammal vocalizations were classified from audio clips of both instruments. Classifications from the PAL were made from the sound clips, and AURAL classifications were made from the results of two frequency band energy detectors. Four days from each month (1st, 8th, 15th and 23rd) from October 2008 through May 2009 were selected for comparison. The presence of marine mammal vocalizations for each day was tabulated independently for the audio recordings from each system.

Spectra clusters associated with saved soundbites were used to develop templates of stereotyped vocalizations. Species with stereotyped vocalizations considered were bearded seals, ribbon seals, bowhead whales, and Pacific walrus (Risch et al., 2007). In PAL spectra clusters, bearded seal trills manifested as a two to three bin wide peaks descending in frequency in all 8 spectral samples from a 4.5 second soundbite. Ribbon seal downsweeps have energy in frequencies from 200 Hz to 5 kHz and average duration of 2 seconds (Watkins and Ray, 1977; Miksis-Olds & Parks, 2011). These downsweeps manifested as a series of up to three narrow peaks descending in frequency over a subset of the PAL spectral samples. Bowhead whale moans and songs contain energy in frequencies below 5 kHz (Cummings & Holliday, 1987). During classification, spectra clusters were displayed in random order without date stamps to prevent bias. Species classifications were recorded from user input in Matlab. If the human classifier observed a pattern matching the template for one of the species in a spectral cluster, the classification was recorded. Spectra clusters computed from saved soundbites were included in the classification process for groundtruthing purposes. Recall and false alarm rates were calculated to quantify the classification performance from spectra. Recall rate was the proportion of the clips previously identified in soundbites as containing a vocalization also classified using the spectral methods. False alarm rate was the proportion of the clips classified using the spectral methods in which the vocalization identified was not actually present.

To assess patterns and variability of physical and biological parameters in different regions of the water column, mean volume backscatter coefficient (mean s_v in units m^2/m^3) was calculated from integrations in both 24 hour and 30 minute bins over 5 m depth layers and from identified region subsets within individual aggregations using EchoView software (Myriax, Tasmania). Theoretical scattering curves for four different types of individual scatterers were generated and dB-differences at the three acoustic frequencies used in this study were calculated. Scattering amplitudes (and the subsequent dB differences at 125, 200, and 460 kHz) were generated using a Stochastic Distorted Wave Born Approximation model (Demer & Conti, 2003) for the following scatterers: 1) small scatterers such as copepods (lengths of 1 – 5 mm), 2) medium scatterers (lengths of 5 – 15 mm) which includes juvenile krill, chaetognaths, and amphipods, 3) large scatterers such as adult euphausiids (lengths of 15 - 30 mm), 4) resonant scatterers, and 5) unknown. The acoustic system was not able to detect the weak scattering strengths of scatterers less than approximately 5mm in length unless they were present in extremely dense aggregations. Neretic copepod species typically found over the middle shelf (*Pseudocalanus* spp., *Acartia longiremis, Oithona* spp. and *Calanus*) are less than 5mm (Gardner & Szabo, 1982; Coyle & Pinchuk, 2002) and comprised the small scatterer category. The resonant scatterer type represents an organism with a gas-inclusion such as a swim-bladdered fish or siphonophore which has a strong resonant peak in the scattering spectra (Stanton, 1998). Aggregations were classified as belonging to one of the five categories (small, medium, or large scatterer; resonant; or unknown) by determining the shortest geometric distance between the three dB differences calculated for the aggregation and that of the theoretical scatterers. If the closest geometric distance was more than 12 dB (an arbitrarily chosen value), then the aggregation was classified as unknown.

Numerical density was estimated using the mean s_v from the 200 kHz echo signals within each integrated volume assuming all single taxa aggregations based on the results of the dB difference size classification. The number of scatterers (N) was calculated by $N = s_v//\sigma_{bs}$. Vertical and oblique net tows were conducted to collect zooplankton at each mooring site during the mooring maintenance cruises to identify dominant species, species composition, and numerical density during mooring deployments and recoveries to guide acoustic modeling and compare to acoustic estimates.

Modeling

Presence-absence data for each species identified in the passive acoustic recordings was the response variable in the generalized linear and generalized additive mixed models (GLMM and GAMM) designed to identify predictor variables of species presence. Initial models included all predictor variables collected (except wind): ice thickness, % ice cover, 200 kHz Sv, % prey composition (small, medium, large, and resonant scatterers), and sound level (500 Hz, 2 kHz, 10 kHz, 20 kHz, 40 kHz). Data was first explored to identify potential outliers and evaluate distribution and collinearity among predictor variables and also with marine mammal presence using functions of the AED package in R (Zuur, 2010). Explanatory variables were centered to allow better model convergence and interpretation, with the exception of ice cover and thickness. Ice cover and ice thickness showed a zero-inflated distribution and transformations failed to sufficiently address the skewed distributions. Zero values are meaningful for these measurements and thus these variables were not truncated or transformed. High collinearity was found between environmental sound variables with the correlation highest between close frequencies. Ice cover and ice thickness were also highly collinear, although one or both of these variables were removed from the models during the selection process so this collinearity did not pose a problem. Final models including multiple noise variables were checked for collinearity using the *corvif* function from the R package *AED* (Zuur, 2010). All variables included in final models had VIFs well below 10 (the maximum VIF was 2.32), indicating sufficiently low collinearity (Chatterjee & Hadi, 2006).

Generalized linear models (GLMs) and generalized additive models (GAMs) allow model fitting to describe relationships between variables without constraints of linear regression models (McCullagh & Nelder, 1989). Generalized additive mixed models (GAMMs) and generalized linear mixed models (GLMMs) extend GAMs and GLMs to include random effects and correlation structures to deal with violations of independence that are often present in observational and time series data and are becoming popular in the analysis of ecological data (for example: Friedlaender et al., 2006; Wagner & Sweka, 2011). GLMs and GLMMs with a binomial distribution and logit link function were fit using a backward stepwise approach. Variables were selected for removal using the *drop1* command from the basic *stats* package in R (version 2.14.1; R Development Core Team, 2011) to apply an analysis of deviance test following a Chi-square distribution. Variables were removed based on a significance criteria of $p<0.01$ until all variables in the model were considered significant. Significance tests and p-values for analysis of deviance are approximate, thus a selection criteria below the standard 95% significance level was used to avoid inclusion of unnecessary terms. GLMMs were fit using the *glmmPQL* function from the *MASS* package in R (Venables & Ripley, 2002). This approach allowed the inclusion of a random effect for site to allow inference beyond the two stations sampled and a temporal correlation structure to address the lack of independence due to repeated sampling at each site. Convergence problems were frequently encountered when a temporal correlation structure for date grouped by site was included. Auto-correlation in the model residuals was examined to determine whether the temporal correlation structure was needed, as including a random effect for site imposes an implicit compound symmetry correlation structure that assumes a constant correlation within data points from the same site. GAMs and GAMMs with a binomial distribution and logit link function were fit using the same procedure described above with the *gamm* function from the *mgcv* package in R (Wood, 2006; Wood, 2011) to explore potential non-linear relationships.

GLMM and GAMM techniques are on the "frontier of statistical research" and as such model selection and validation for generalized models on absence-presence response data is difficult (Zuur et al., 2009). Standardized residuals were extracted and plotted against predictor variables and fitted values to look for patterns. Greater variation in residuals at zero ice coverage was discovered, likely due to the large number of zero values for ice cover. A new data set, zero-truncated for ice cover, was then used to fit the final models to explore the potential for zero values to interfere with model function and selection.

RESULTS

Expansion A (PAL performance)

PAL deployments in the Bering Sea demonstrated the feasibility of detecting of marine mammal signals within a dynamic background sound field using an adaptive sub-sampling protocol (Miksis-Olds et al., 2010). Onboard processing algorithms automatically detected and classified transient signals. In addition to the automatic detections, post-processing of the soundbites revealed secondary marine mammal detections. These secondary detections demonstrate the wealth of information that can be obtained from short sound clips. Species with high vocalization rates and long calling bouts (fin whales, bowhead whales, and bearded seals) were more likely to be recorded incidentally compared to species with low vocalization rates and short calling bouts (right whales). However, the low 1.5% duty cycle was adequate for detecting right whale presence (Miksis-Olds et al., 2010) and describing 2 new ribbon seal vocalizations (Miksis-Olds & Parks, 2011). Acknowledging that physical propagation characteristics associated with detectability must also be addressed, this work illustrates how the combination of spectral data and short sound clips obtained with small, low duty cycle recorders can provide the information needed to address questions of species richness, temporal presence of animals, and response to changes in the environment without the large volume of data obtained by continuous recorders.

Data from the PAL and AURAL recorders were analyzed on 32 days during an eight month deployment. Table 1 summarizes the species detected and breakdown of detections by instrument. Of the species identified from the PAL spectra clusters, only classifications for bearded and ribbon seals were included in the daily counts. Classification of bearded seal vocalizations from spectra clusters led to an additional 3 detection days for the PAL with a recall rate of 11% and a false alarm rate of 3%. Classification of ribbon seal vocalizations from the spectra led to an additional 4 detection days for the PAL with a recall rate of 7% and a false alarm rate of 2%. Despite repeated efforts at improvement in identification of walrus and bowhead whale spectral patterns, recall rates never exceeded false alarm rates for these classifications from spectra clusters. Therefore, no additional detection days for these species were included (Denes et al., submitted 6/2012).

Table 1. Total number of days detected for each vocalization category by instrument

	Total Days Detected	Days Detected by AURAL only	Days Detected by PAL only	Days Detected by Both
Bowhead Whales	21	3	0	18
Humpback Whales	9	4	4	1
Odontocetes	7	3	2	2
Bearded Seals	17	1	0	16
Walrus	12	7	1	4
Ribbon Seals	12	0	1	11
Echolocation clicks	18	0	18	0

Originally Proposed Research and Expansion B

The ambient sound levels and overall acoustic activity were highly seasonal and dependent on ice and wind conditions (Figures 4, 5, and 6) (Miksis-Olds et al., accepted). Level of acoustic activity was identified by the number of hourly transient signal detections (Figure 5). Most of the transient detections were attributed to ice movement and animal vocalizations, as geophysical sounds (e.g. wind, rain, melting ice) generally have time scales longer than 4.5 seconds. Two types of ice-generated sounds were associated with movement: 1) very loud harmonic screeching/squeaking sounds of ice floes grating together (Figure 6B), and 2) broadband, rapid rise time signals of ice floe cracking and bumping. During periods of open water very few transients were detected compared to ice covered periods. During periods of ice presence, high numbers of transients were recorded; thus, periods with sea ice are easily depicted in the ambient sound record based on transient sound triggers alone (Figure 4). Transient detection rate during the final melting phase was low, but persistent. If you summed the area under the curve in Figure 5 during this period, it approximates or may even exceed the level of transient detections observed during the retreat period.

There were discernible differences between the two sites in terms of detected sources and overall sound levels and patterns. During open water period of the summer and fall, more boating activity and baleen whale vocalizations were detected in the southeastern region of the Bering Sea shelf compared to the central location (Miksis-Olds et al., 2010) which contributed to louder ambient levels at the M2 location during open water periods (Figure 7). The southern location was also generally louder over the course of a year because the ice cover was less extensive at the southern location compared to the central shelf region. Although transient detections and overall sound level variability were higher when ice was present, ambient sound levels tended to be lower when the surface conditions were solid ice above the mooring (Figures 4, 6, and 7).

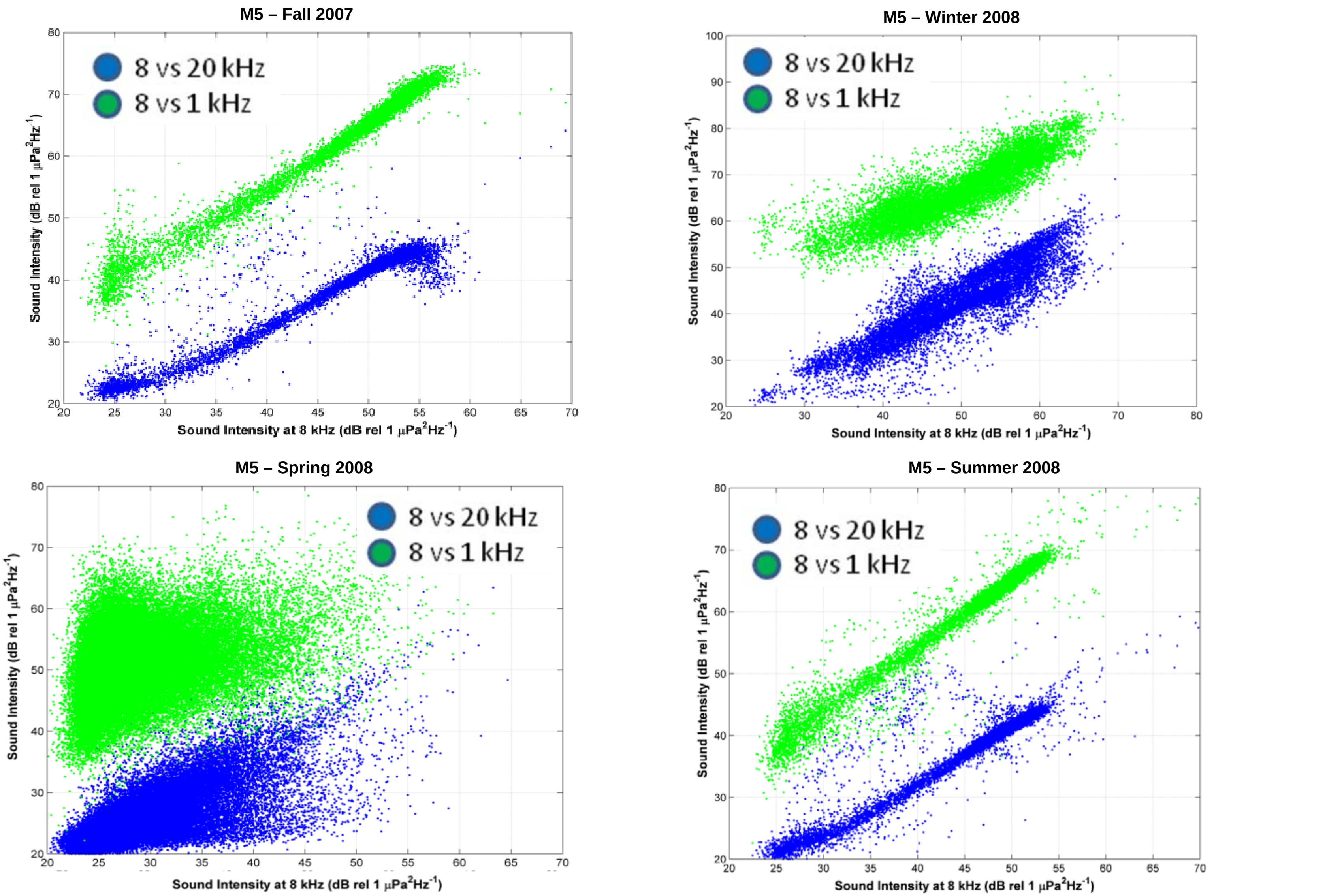

Figure 4. Seasoanl soundscapes generated from spectral data. The x axis in all panels is the sound level at 8 kHz. The y axis is the sound level at either 20 kHz (blue) or 1 kHz (green). The soundscapes in fall (a) and summer (d) show a linear pattern indicating an environment dominated by wind. Sound levels increase linearly as wind speed increases. The spectral variability in winter (b) is due to bowhead song, while in spring (c) vocalizations from breeding ice seals dominate the soundscape.

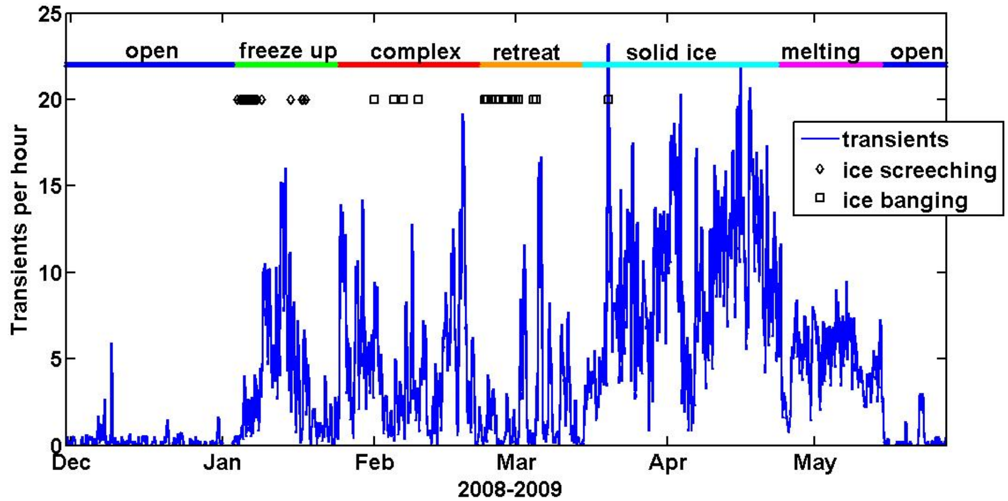

Figure 5. Time series of transient signal detections by the PAL at M5. Open water and five periods of ice conditions are indicated with color bars running along the top of the figure.

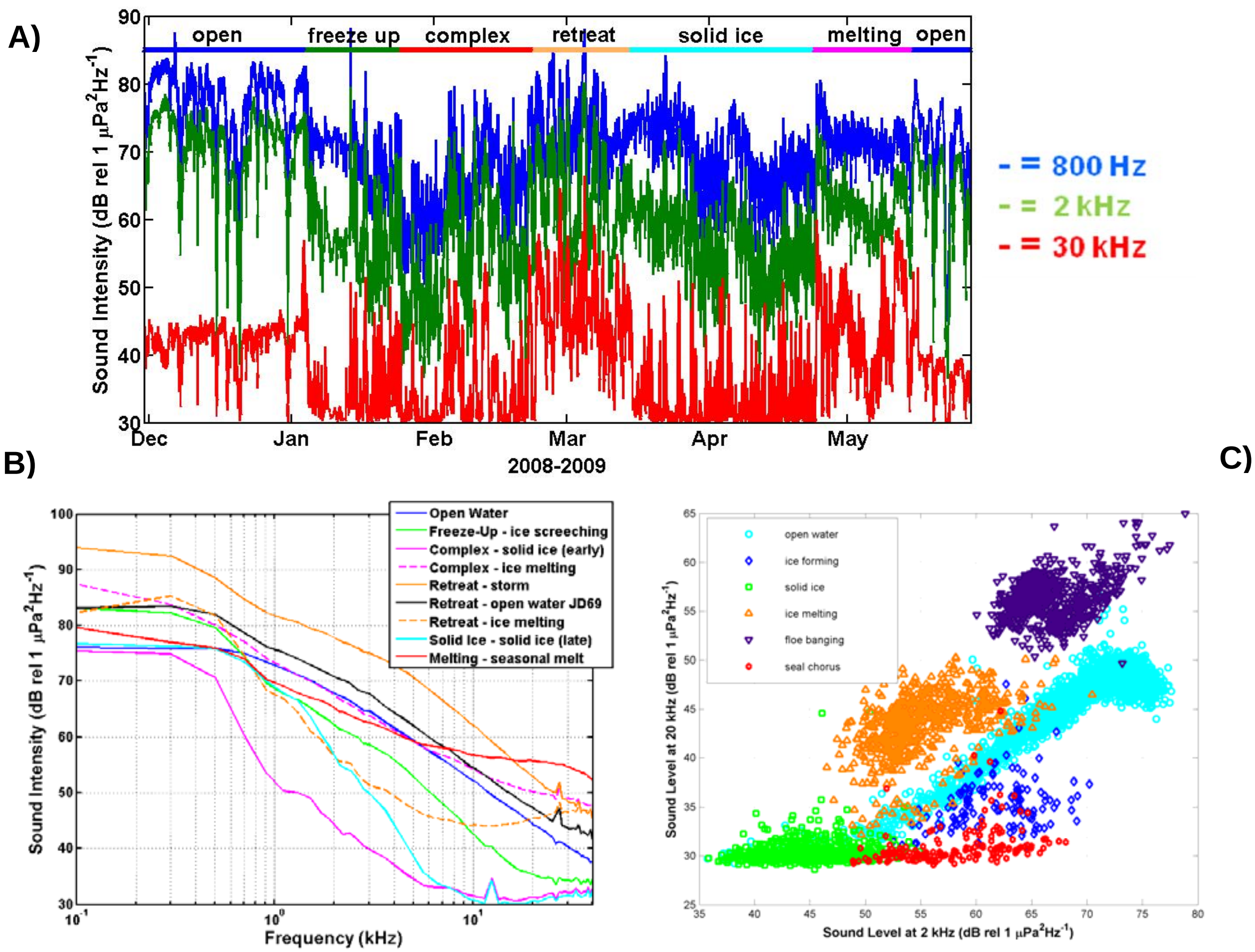

Figure 6. A) Time series of sound levels at during the 2008-2009 deployment at location M5. Open water and five periods of ice conditions are indicated with color bars running along the top of the figure. The color of each surface category is coordinated with representative spectra identified during the associated periods in (B) and shown visually in the corresponding soundscape in (C).

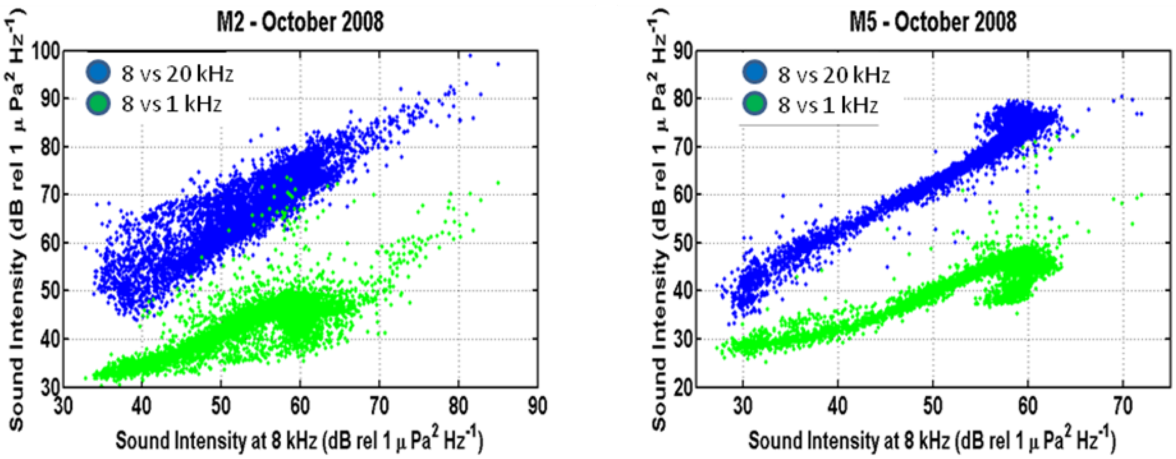

Figure 7. Soundscapes from M2 and M5 during October 2008 under open water conditions. The axes differ between the soundscapes and highlight the louder more variable acoustic environment at M2 due to vessel presence and marine mammal vocalizations.

The year-round deployment of the acoustic sensors in close proximity to the oceanographic mooring created an observation system that was able to document previously unobserved coupling of physical and biological processes under ice. The relationship between zooplankton/fish dynamics and physical processes related to wind, storms, and ice cover were most clearly illustrated during an unexpected, transient, mid-winter retreat of the seasonal sea ice over the M5 mooring for a two-week period in March 2009 (Miksis-Olds et al., accepted) (Figure 8). Changes in zooplankton dynamics were observed amidst a physically stable and uniform water column with no indication of a phytoplankton bloom (Figure 9). The level of acoustic backscatter in the upper portion of the water column prior to and during the retreat was relatively consistent. The uniform levels of acoustic backscatter in the upper water column may have been due to a combination of under-ice algae and maintenance of position by zooplankton in the upper water column. The increase in acoustic backscatter intensity by over an order of magnitude over the full water column and in the lower portion of the water column at the beginning of the retreat period was unexpected and inconsistent with patterns reported for the seasonal ice retreat (i.e. an absence of thermal or salinity induced stratification, initiation of a spring phytoplankton bloom with elevated chlorophyll, and corresponding increases in secondary production) (Figure 9) (Niebauer et al., 1999; Stabeno et al., 2012a). This demonstrates how rapidly the zooplankton community can change in response to short-term environmental changes.

Backscatter throughout the water column was estimated to consist of medium-sized scatterers representative of chaetognaths and resonant scatterers indicative of fish in approximately equal amounts. Community structure observed during the retreat was almost identical to the community structure observed in December 2008 prior to the seasonal ice advance, and very different from the community structure following the seasonal ice retreat which was dominated by medium-sized scatterers (Table 2). Results of net tows conducted a month after the retreat showed that chaetognaths (*Sagitta elegans*) were indeed a large proportion of the biomass in the 5-15 mm size category even though small copepods (< 5mm; *Pseudocalanus* spp., etc) were numerically dominant. The lack of corresponding estimates from our acoustic data for the smaller crustaceans was most likely due to the fact that the weak scattering levels of the smaller animals using our three frequencies was not sufficient enough to be detected acoustically unless they were encountered in extremely high numerical densities.

Diel vertical migration (DVM) behavior was observed throughout the acoustic time series both under ice and in open water (Figures 8 and 12). Adult *Calanus* in the Bering Sea and North Pacific are known to perform diel vertical migrations (e.g. Schabetsberger et al., 2000; Lamb & Peterson, 2005), while *A. longiremis* remains in the upper layer both day and night (Mackas & Galbraith, 2002). Therefore, the increase in DVM detected during the retreat provides support for the presence of *Calanus*, assuming that the early life history stages of *Thysanoessa raschii* were not yet present (Smith, 1991).

The combination of multi-frequency acoustic analysis and net tow information acquired as close as possible to the mooring location at the time of the retreat suggests that the large increase in volume backscatter observed in the lower portion of the water column during the retreat was due to an increase in chaetognath and copepod abundance, as well as potential predatory fish indicated by the presence of resonant scatterers. The sharp increase could be attributed to: 1) advection of a new water mass into the region, 2) a change in vertical distribution of scatterers from below the deepest depth ensonified by the acoustics to a new shallower depth, or 3) a rapid increase in their abundance during the ice retreat. If the observed increase in deep water backscatter during the temporary ice retreat was due to a local increase in small copepod numerical density, and not due to advection or repositioning of zooplankton in the water column, then it is inconsistent with the hypothesis that temperature is the most important variable influencing small copepod production in the Bering Sea and in other oceans (Smith & Vidal, 1986; Hirst et al., 2003). In this study, the increase in backscatter was not accompanied by an increase in temperature prior to or at the beginning of the temporary retreat period. The overall backscatter increase throughout the water column during the retreat also indicated that the observed deep layer increase in volume backscatter was not due to a simple repositioning of animals from shallower depths. What caused the increase in deep water backscatter coincident with the temporary ice retreat is unknown and requires further investigation of under-ice dynamics over the winter.

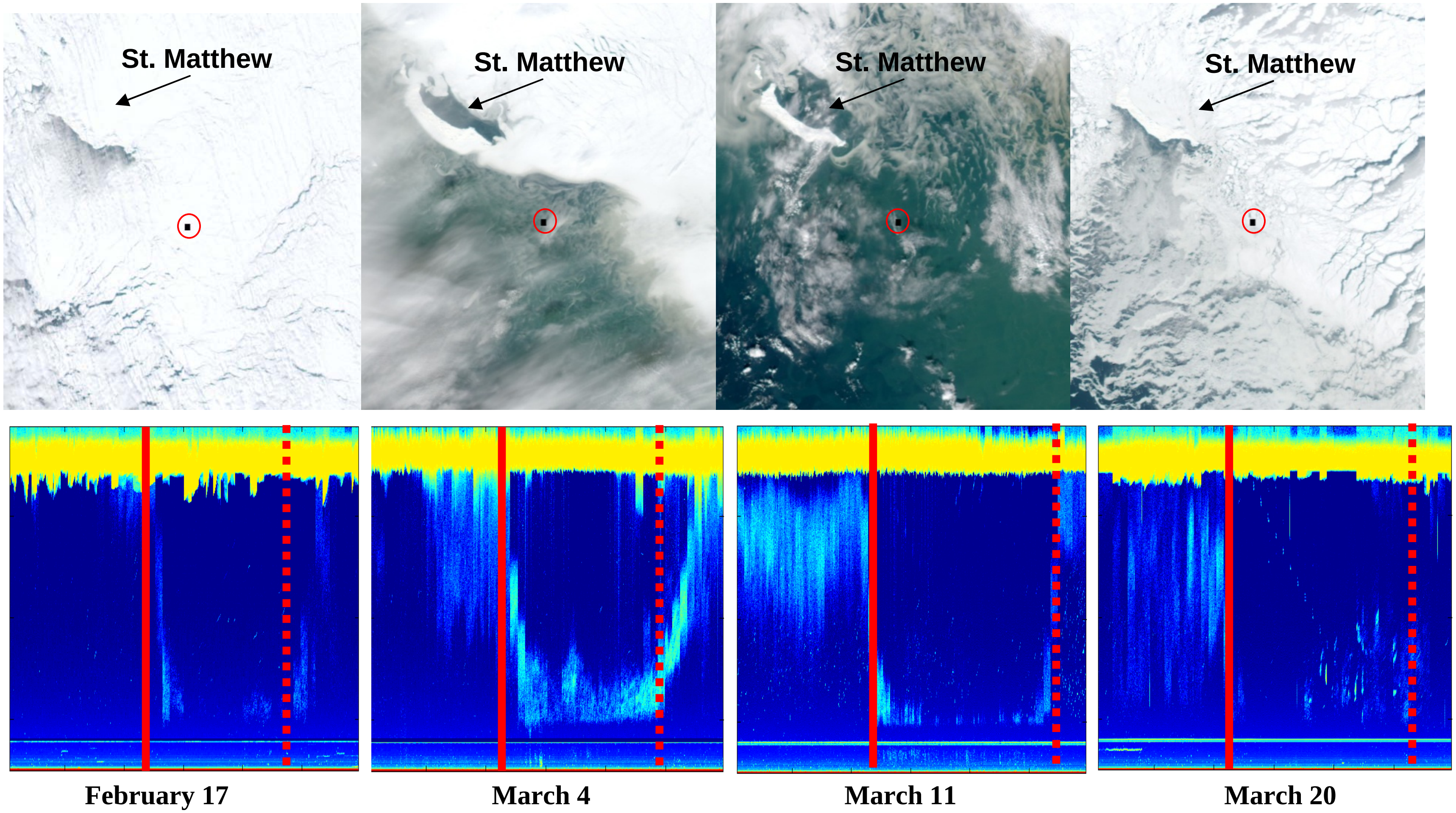

Figure 8. Satellite image photo series of ice cover and corresponding 24-hour echogram (200 kHz) over mooring M5 in winter 2009. The mooring location is denoted by the black point with a red circle. The solid and dashed lines on echograms denote sunrise and sunset, **respectively.** *Vertical migrations are present under ice and during open water periods.*

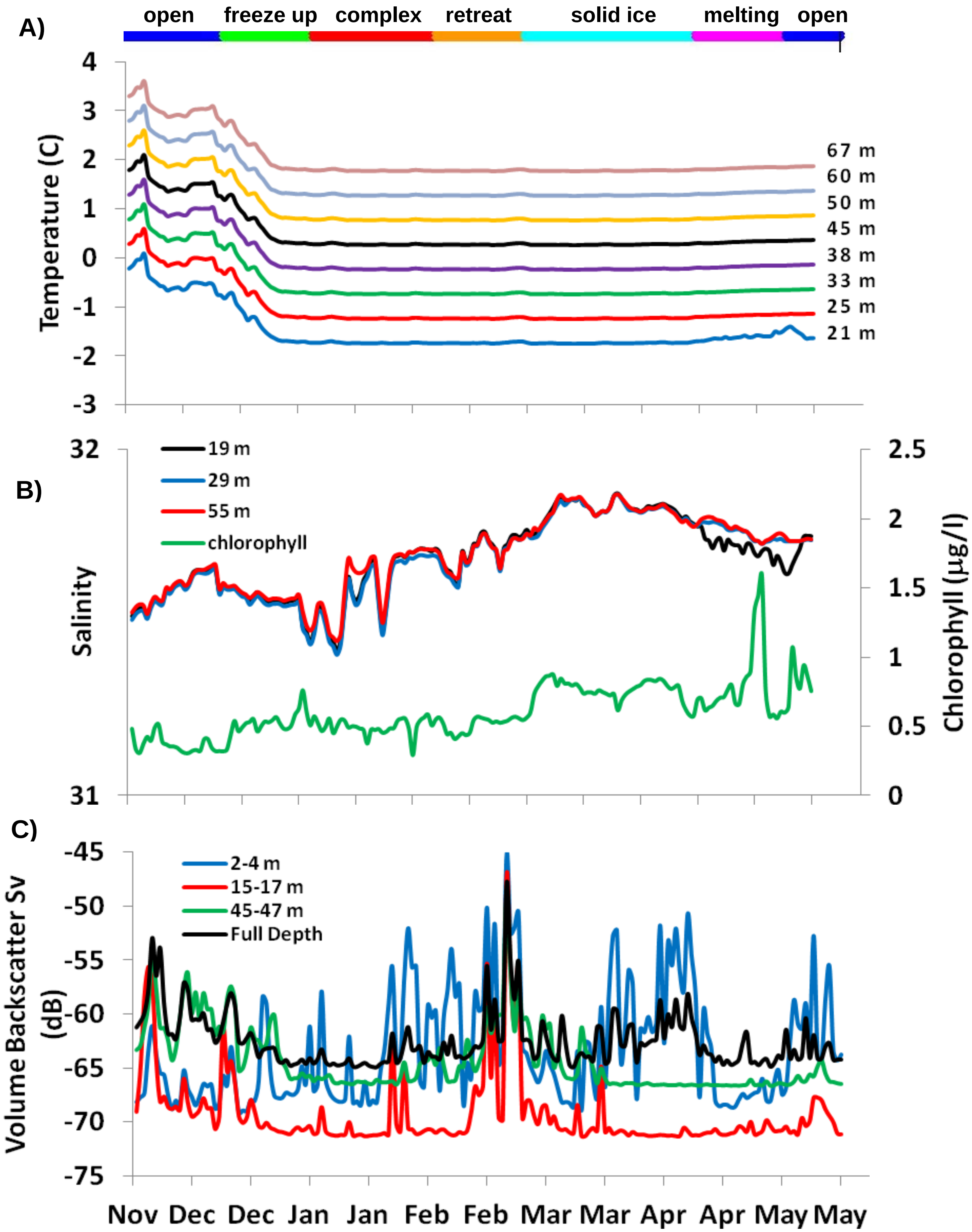

Figure 9. Time series of temperature (A), salinity and estimated chlorophyll concentration at 20 m (B), and 460 kHz volume backscatter (C) from December 2008–May 2009. There is a 0.5 °C offset between the temperature time series at each depth. Temperature, salinity, estimated chlorophyll, and volume backscatter values represent daily averages. The horizontal bar running across the top of the panel indicates surface conditions.

Table 2. Classification of aggregations based on geometric distance between measured dB-differences and five different categories: small scatterers (copepods), medium scatterers (large copepods, amphipods, chaetognaths, and juvenile krill), large scatterers (adult krill), resonant scatterers (fish, siphonophores, bubbles), unclassified.

Period (# aggregations)	% Small Scatterers	% Medium Scatterers	% Large Scatterers	% Resonant	% Unclassified
Dec 2008 (37)	0	41	3	49	8
Mar 2009 (58)	0	47	3	45	5
May 2009 (46)	0	72	0	28	0

The integration of acoustic, satellite, and oceanographic information has provided insight on environmental parameters and patterns corresponding to marine mammal presence and vocal behavior. Full ecosystem monitoring through the use of acoustic technology provided the relevant context for interpreting marine mammal vocal detection patterns and identifying the combination of factors most strongly associated with marine mammal presence and habitat use along the eastern Bering Sea Shelf. The presence of vocal marine mammals detected in the Bering was tightly coupled to the ice and fall zooplankton bloom (Figures 10 and 11). The relationship between ice and ice-dependent marine mammals was clearly demonstrated by the absence of bearded and ribbon seal detections during the two weeks of the temporary retreat in 2009 (Figure 10). When the ice returned after the rapid retreat, bearded seals were detected almost immediately, whereas ribbon seal vocalizations were not regularly detected again until the ice was thicker than 20 inches (Figure 10). This suggests that ice utilization by ice seals is species dependent and related to specific characteristics of the ice.

In the southeastern region (M2) blue whales and fin whales were detected all year with peak detections corresponding to the spring and fall zooplankton blooms. These species were not detected at any time at M5. Gray and bowhead whales were detected at both locations. The zooplankton community structure differed between the two sites and the same patterns were not observed from year to year despite all years in the study being characterized as cold years with high ice extent (Stabeno et al., 2012) (Figures 12 and 13).

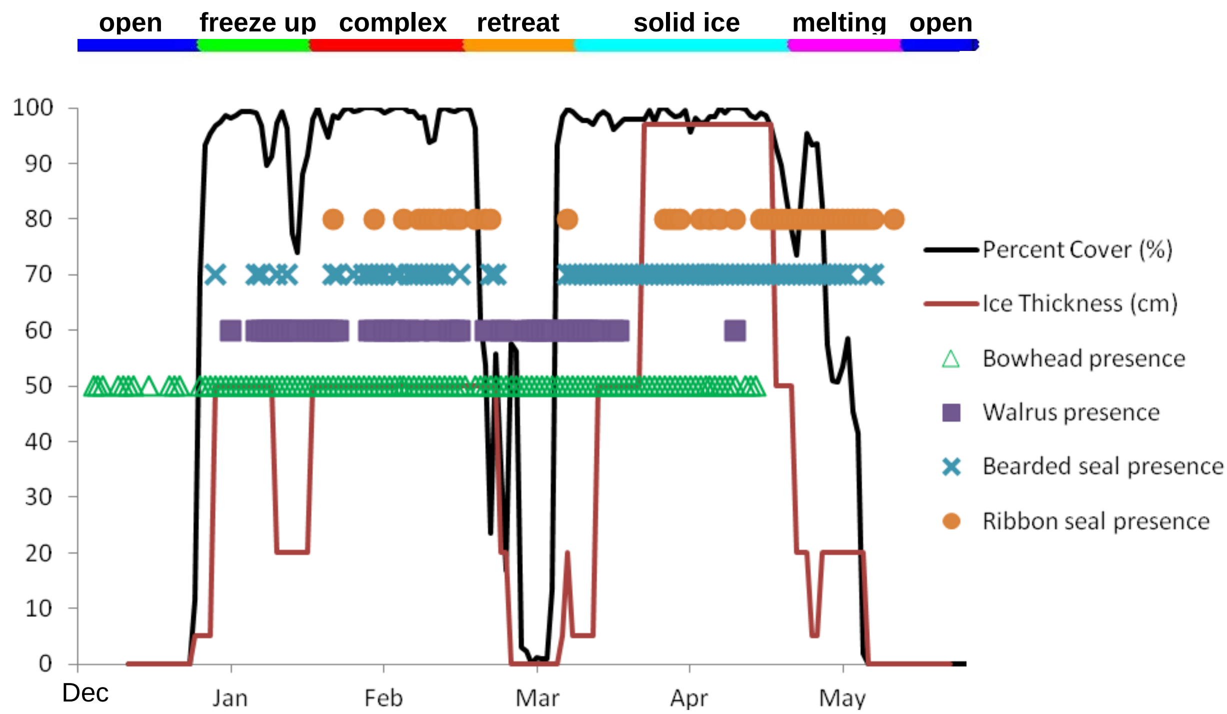

Figure 10. Time series of ice presence over the M5 mooring during the 2008-2009 winter season. A temporary ice retreat was observed in March 2009 that persisted for approximately 2 weeks. Acoustic presence of species does not correspond to a numerical value on the y axis. The species-specific symbols reflect daily acoustic presence and are separated spatially for easy visualization. The horizontal bar running across the top indicates estimated surface conditions above the mooring.

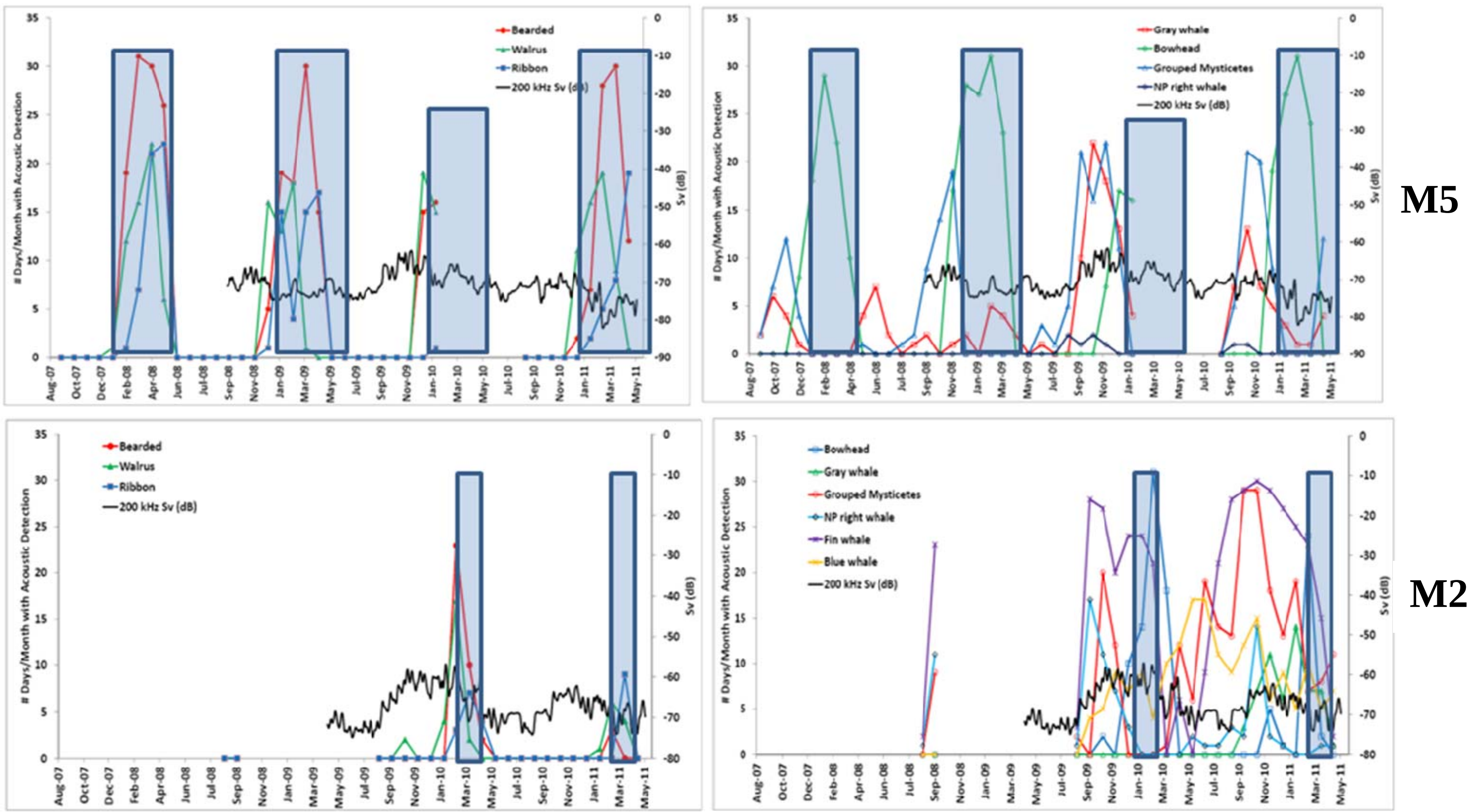

Figure 11. Monthly acoustic detections of marine mammal species at M5 (top panels) and M2 (bottom panels). Pinniped species (left panels) are shown separately from cetacean species (right panels). The blue rectangles indicate the presence of ice above the mooring, and the 200 kHz Sv time series for each location is shown in each panel on the secondary y axis. Pinniped and bohead whale detections were associated with ice presence, whereas non-bowhead mysticete detections were assocaited with the fall zooplankton blooms.

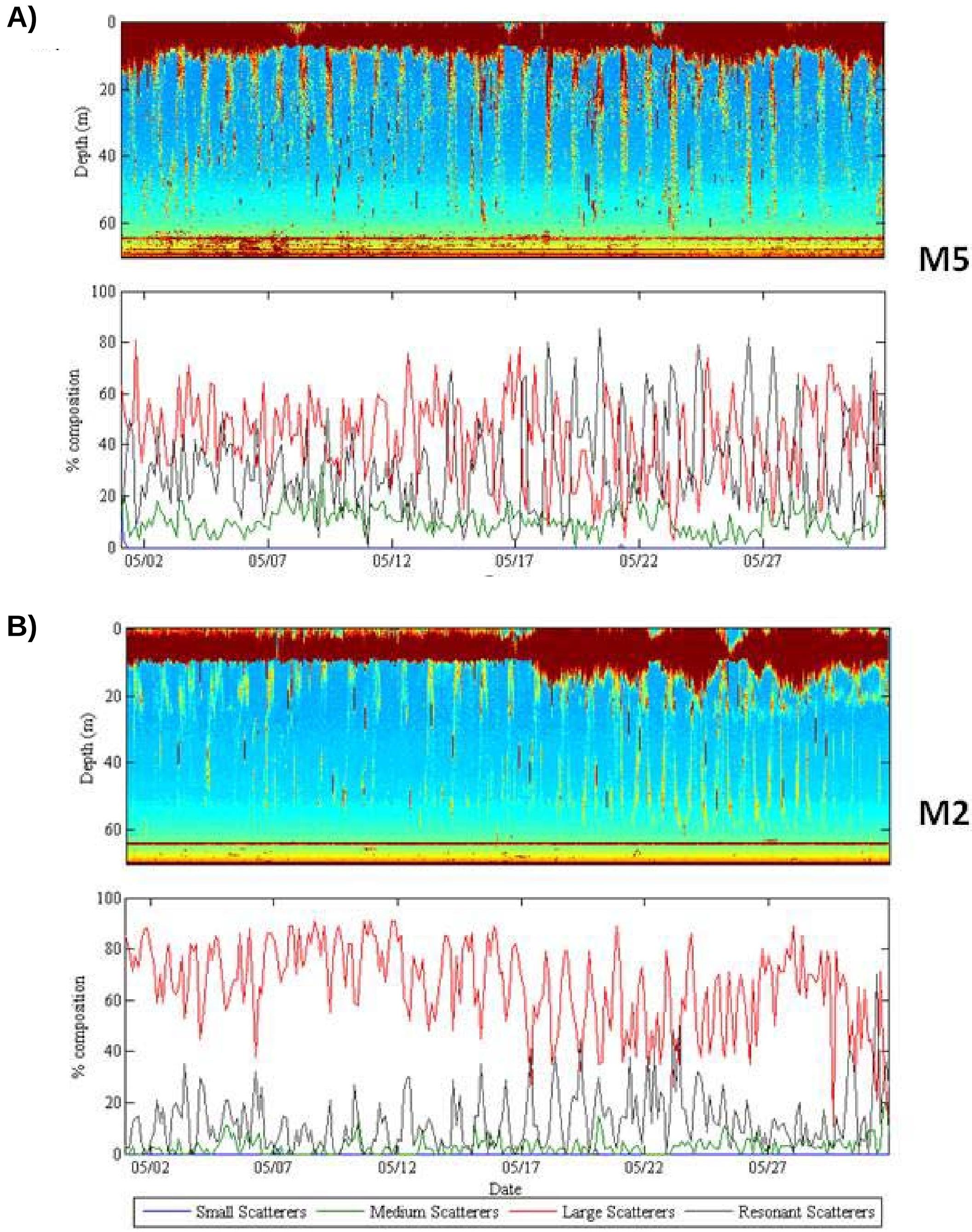

Figure 12. Month long echogram (200 kHz) with time aligned percent species composition at mooring location M5 (A) and M2 (B) in May 2009. Diel vertical migration patterns are evident at both sites.

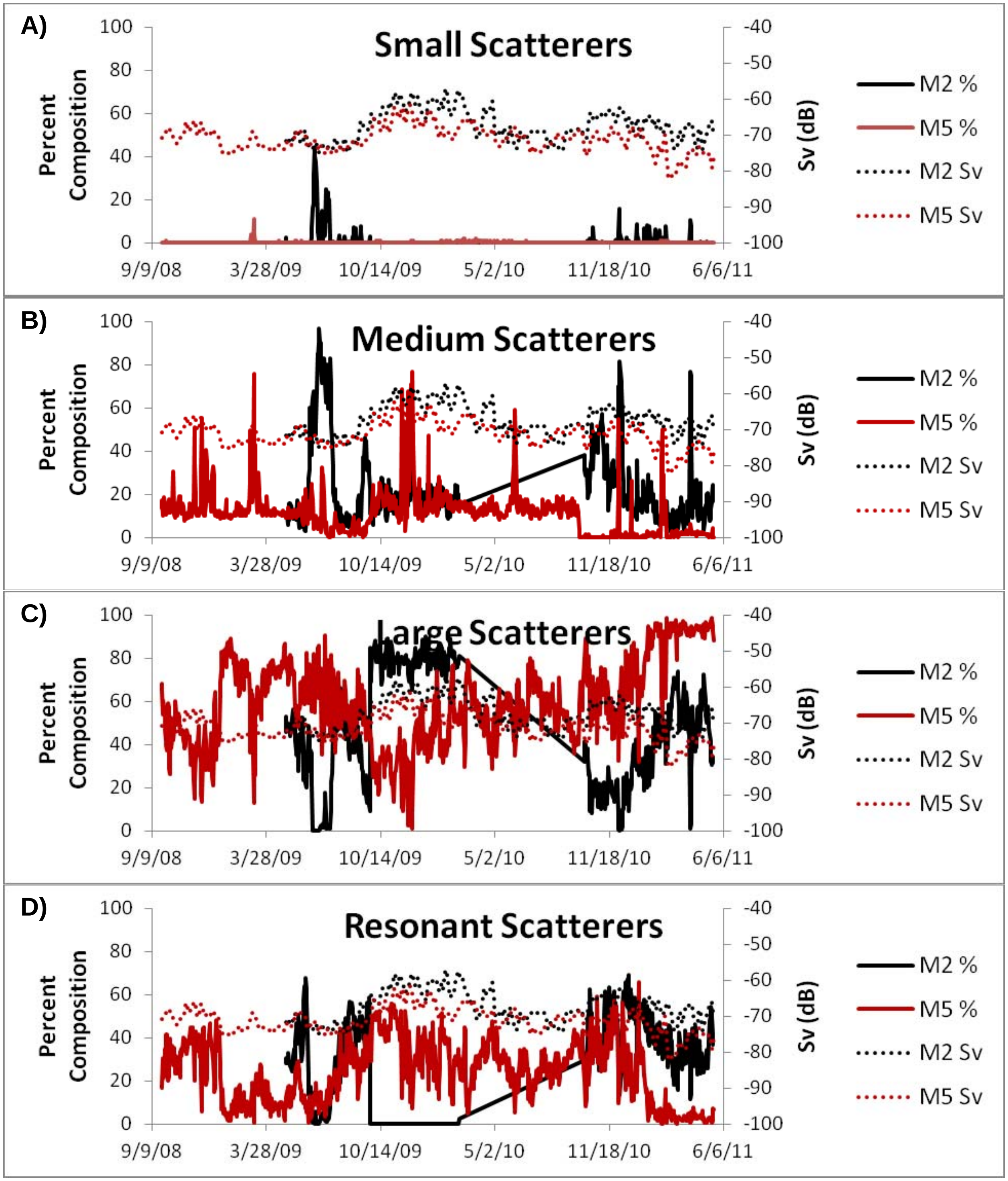

Figure 13. Percent composition and Sv times series estimated at mooring locations M2 and M5 for small (A), medium (B), large (C) sized scatterers, and resonant scatterers (D). Annual trends in Sv are observed at each site, but this does not translate into annual trends in percent composition at each site.

Predictors of Marine Mammal Presence: Seals

Environmental parameters predictive of species presence were identified through a series of mixed models. The final GLM and GLMM model for ice seals (combination of ribbon and bearded seals) both included ice cover, 10 kHz sound, 40 kHz sound and an interaction between ice cover and large crustaceans as significant predictors of ice seal presence. Ice seal presence showed a strong positive correlation with ice cover and a negative association with 10 kHz environmental sound (Figure 14). Prey alone was not a good predictor of seal presence and an interaction between ice cover and large crustaceans indicates a negative relationship with seal presence, likely due to the somewhat non-linear relationship between ice seals and ice cover at M5. Parameters estimated by both the GLM and GLMM are nearly identical, suggesting little difference between M2 and M5. However, the inclusion of a random site effect in the GLMM was highly effective in addressing residual autocorrelation. The inclusion of a temporal correlation structure in the GLMM reduced numerical stability (increased non-convergence problems) and captured less of the residual auto-correlation in the final model. The GLMM with a random site effect and no temporal correlation structure was selected as the optimal model.

GAMM models showed primarily linear relationships between seal presence and ice cover and 10 kHz sound, with the exception of ice cover at M5 (Figure 14). The final GAMM model included smooth terms for ice cover and 10 kHz sound with a random smoother for ice cover. Including random smoothers for ice cover and 10 kHz sound resulted in neither 10 kHz smoother being significant. All GAMM models with 40 kHz sound failed to converge. Figure 14B suggests a non-linear effect of ice cover on seal presence as the increasing trend in the smoother levels around 50 percent cover. However, 2.52 degrees of freedom alone is not strong evidence against a GAMM (Zuur et al., 2009), and this relationship must also be regarded with caution as non-convergence issues disallowed inclusion of all predictor variables of interest in the fitting of this model. As a result, the GLMM with a random site effect was selected as the optimal model for this data. Ice cover and 10 kHz sound level appear to be significant predictors of seal presence, with 40 kHz sound and prey presence (combined with ice cover) as potential predictors as well.

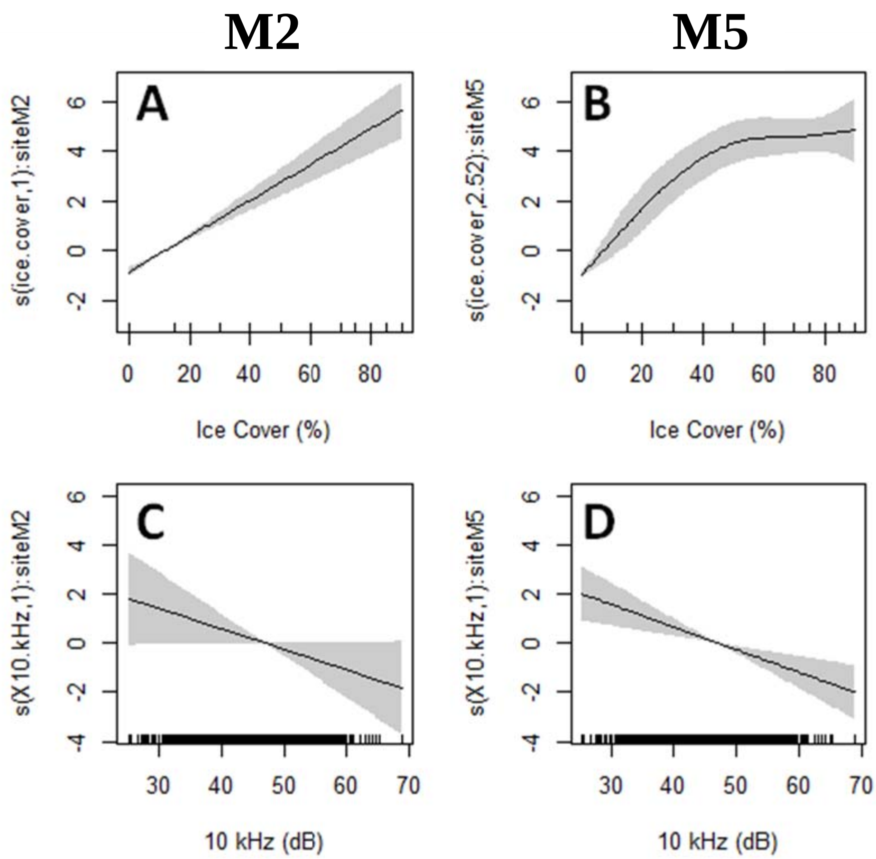

Figure 14. GAMM comparison of smooth functions by site for (A-B) percent ice cover and (C-D) 10 kHz sound. Shaded areas denote 95% confidence intervals. Increase in ice seal presence slows beyond 50% ice cover at M5 (B), although the relationship is still generally linear.

<u>Predictors of Marine Mammal Presence: Whales</u>

Initial models included all predictor variables collected (except wind). The selected model included medium crustaceans and weak resonators as significant predictors of gray whale presence. Ice thickness and 2 kHz noise were negatively associated with gray whale presence at M5 and may be potential predictors as well. A general additive model (GAM) was then fitted to examine the potential non-linear effect of 2 kHz noise on gray whale presence at M5. Figure 15 shows an increasing negative effect on gray whale presence as the 2 kHz sound level increases past approximately 65 dB. Models also indicated a positive effect of medium-sized crustacean abundance on gray whale presence. Figure 16 compares the annual trend in both gray whale presence and medium crustacean abundance at M5. These GAMs include only the 'day of the year' smoother and no other predictor variables. The two major peaks in gray whale presence occur around the time of the two largest peaks in medium crustacean abundance and appear to be a strong predictor of gray whale presence across sites.

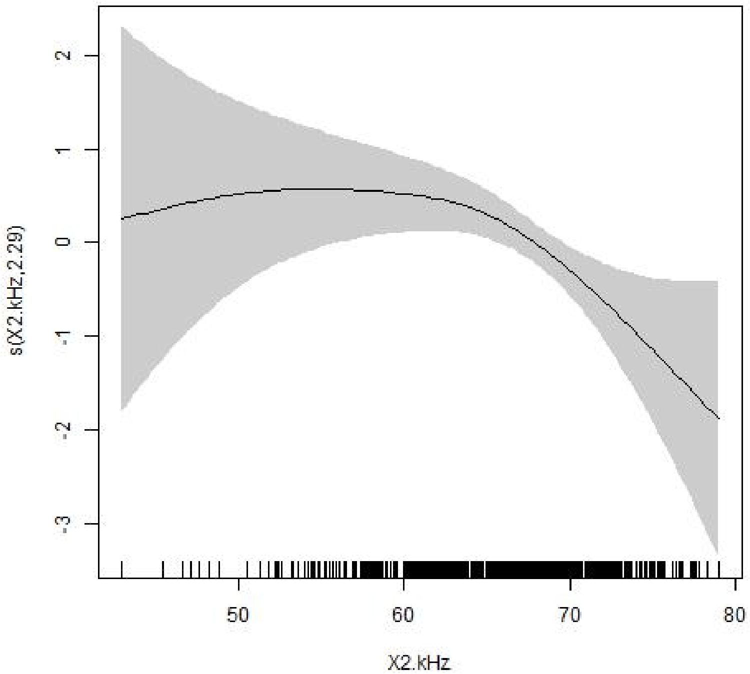

Figure 15. Effect of 2 kHz environmental noise on gray whale presence. The solid line depicts the smooth function representing the effect of 2 kHz (in dB) noise on gray whale presence. The shaded area shows the 95% confidence band around the smooth function. Where the smooth line is above zero, there is a positive effect of 2 kHz noise on presence, and where the line is below zero indicates sound levels of 2 kHz noise associated with a negative effect on presence. The scale of the smoothing effect is shown on the y-axis.

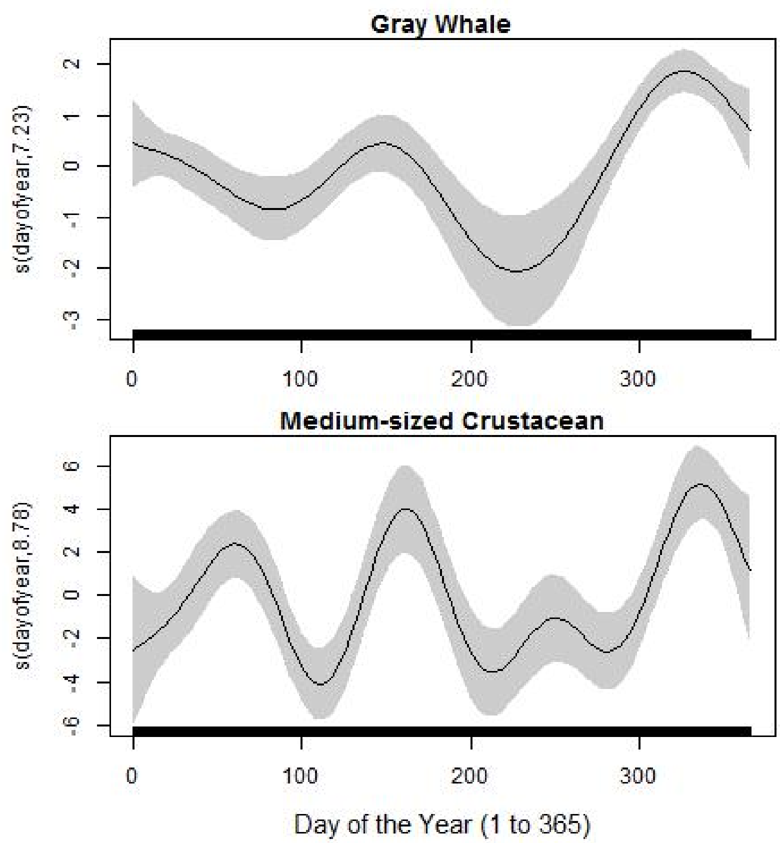

Figure 16. Annual patterns in gray whale presence and medium crustacean abundance. The x-axis shows the day of the year (1 to 365) with 1 representing Jan. 1. The shaded area shows the 95% confidence band around the smooth function. The two major peaks in gray whale detection occurred around the time of the two largest peaks in medium crustacean abundance.

Efforts under ongoing and proposed projects are investigating predictor variables for other species and relating marine mammal presence to observed environmental patterns including numerical density of potential zooplankton prey. (Figure 17).

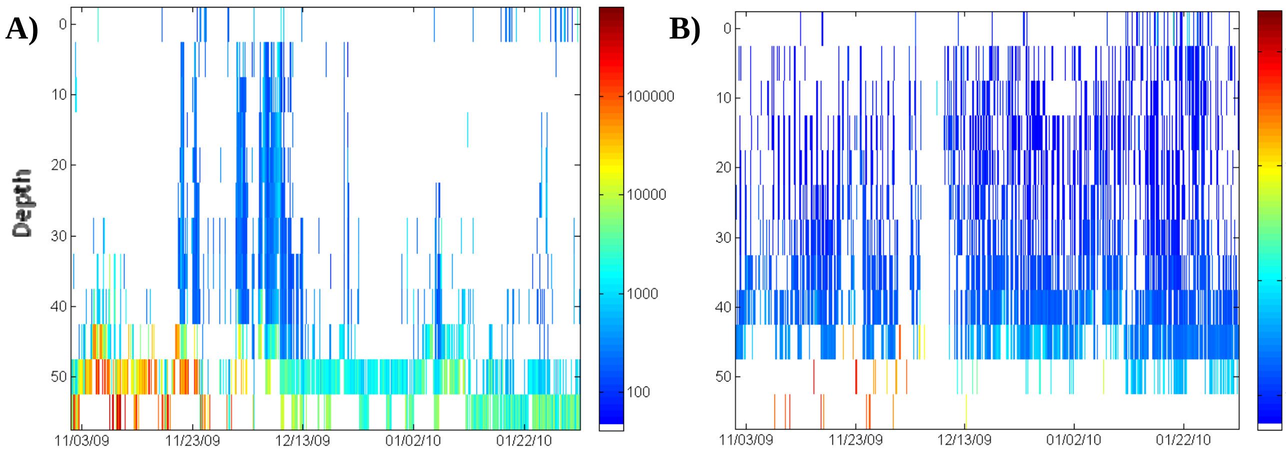

Figure 17. A) Numerical density estimates for medium (A) and large (B) sized scatterers over a three month time period from Nov 2009- Jan 2010 at M5. Estimates were made at a vertical resolution of 5 m. White colors are accurate values representing no scatterers for the size class within that depth bin.

IMPACT/APPLICATIONS

The acoustic measurement system used in this project has the advantage of being deployed for long periods of time on subsurface moorings, affording the opportunity to collect valuable data during the harshest conditions of the winter season when traditional sampling techniques are not possible. The combination of acoustic and environmental datasets revealed that there is a rapid ecosystem response to relatively short-term change in ice cover, which has a profound effect on zooplankton abundance in the deeper water column and marine mammal vocal activity. Identifying relationships between physical forcing mechanisms, biological activity, and marine mammal habitat use will not only be critical in understanding and ultimately predicting how marine mammals respond to noise, but also to how ecosystems respond to variability on multiple time scales.

The system used in this study is appropriate for use in almost all marine environments. It provides an advantage over continuous recording instruments in that the initial real-time processing of environmental sound by the PALs detects and identifies sources of interest without an overwhelming amount of data needing post-processing. The PALs and active acoustic sensors can be programmed to sample at the same time scale to ensure synoptic data collection. The adaptive sub-sampling protocol of the PAL is flexible and can incorporate a wide range of detection algorithms. Under this award, techniques were developed to identify surface ice conditions solely from passive acoustic recordings. Techniques were also developed for the classification of bearded and ribbon seal vocalizations from sparse spectral data without corresponding time series or .wav files. These are significant accomplishments that will support the use of remote sensors and devices under ice and conditions that prevent sustained surface presence to acquire or transmit data.

It is highly likely that the acoustic environment of the Bering Sea and Arctic regions in general will be altered as the area experiences climate changes. The Bering Sea has already experienced significant warming (~3°C) over the last several decades which has been closely associated with a marked decrease in sea ice concentration, duration, and maximum extent over the area (Stabeno et al.

2007; Wang and Overland 2009). Direct climate effects will be linked to ice coverage, and indirect acoustic effects will occur as humans begin to use areas previously inaccessible due to ice. How this will impact the diverse sub-Arctic marine mammal species is unknown, but extreme care should be taken in interpreting the confounding effects of sound on animals in this area as their entire ecosystem will be in a state of flux. Results from this award suggest that both bearded and ribbon seals may be using certain components of the acoustic soundscape to navigate and select appropriate habitats within ice covered waters. Results from this study also highlight the level of zooplankton and fish activity under the ice and present a first look at how dynamics are changing over a yearly cycle. Understanding the details of the relationship between zooplankton/fish, ice, and other environmental parameters under the ice when traditional sampling is not possible will be vital in predicting the impact of change on marine mammal prey that is directly associated with the temporal and spatial extent of marine mammal species.

TRANSITIONS

This project represents a transition from the acoustic (both passive and active) detection and characterization of specific sound sources and scattering targets to the study of ecosystem acoustics and ecosystem response to environmental change. Ecosystem monitoring is especially critical in Arctic and sub-Arctic regions because as climate change impacts these regions, natural ecosystem response will be a confounding factor for any study investigating the impacts of human activity on marine organisms. Techniques developed under the award for 1) remotely identifying surface ice conditions and 2) classifying bearded and ribbon seal vocalizations from sparse spectra in the absence of full acoustic time series. Transition of these techniques to operational activities will be applicable to real-time monitoring and monitoring under conditions that require remote surfacing in ice covered waters and extended surface time to transmit data.

RELATED PROJECTS

All of the equipment used in this research was purchased under DURIP Award N000140810958 titled “Combining active and passive acoustics to study marine mammals”.

Acoustic backscatter measurements from the AWCP instruments will be integrated with ship and satellite measurements of phytoplankton species composition, size structure, and productivity to understand the potential consequences on zooplankton populations measured from moored acoustical observations in a NASA ROSES funded project.

The data acquired under this award will also be further analyzed under a new award proposal to the ONR Marine Mammals Program to support a post-doctoral scholar. The proposed research will classify high-frequency vocalizations to species and correlate the presence of each species with the abundance of fish and zooplankton and ice cover. The final product of this work would combine all measured parameters into a predictive model of odontocete diel and seasonal habitat use of the Bering Sea.

REFERENCES

Brierley, A.S., Saunders, R.A., Bone, D.G., Murphy, E.J., Enderlein, P., Conti, S.G., Demer, D.A. (2006). Use of moored acoustic instruments to measure short-term variability in abundance of Antarctic krill. Limnology and Oceanography: Methods 4, 18-29.

Chatterjee, S., Hadi, A.S. (2006). Regression analysis by example, John Wiley and Sons.

Coyle, K.O., Pinchuk, A.I. (2002). Climate-related differences in zooplankton density and growth on the inner shelf of the southeastern Bering Sea. Progress in Oceanography 55, 177-194.

Cummings, W.C. and D.V. Holliday (1987). Sounds and source levels from bowhead whales off Pt. Barrow, Alaska. Journal of the Acoustical Society of America, 82(3): 814-821.

Demer, D.A., Conti, S.G. (2003). Validation of the stochastic distorted-wave Born approximation model with broad bandwidth total target strength measurements of Antarctic krill. ICES Journal of Marine Science 60, 625-635.

Denes, SL, Miksis-Olds, JL, Mellinger, DK, Nystuen, JA. (submitted 6/2012). A comparison of marine mammal detections from two non-continuous autonomous acoustic recording systems: comparison of sub-sampled acoustic classifications. Special Issue on Methods for Marine Mammal Passive Acoustics, Journal of the Acoustical Society of America.

Friedlaender, A.S., Halpin, P.N. et al. (2006). Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the Western Antarctic Peninsula. Marine Ecological Progress Series, 317: 297-310.

Gardner, G.A., Szabo, I. (1982). British Columbia pelagic marine Copepoda: An identification manual and annotated bibliography. Canadian Special Publication of Fisheries Aquatic Sciences 62, 536 p.

Hirst, A.G., Roff, J.C., Lampitt, R.S. (2003). A synthesis of growth rates in marine epipelagic invertebrate zooplankton. Advances in Marine Biology 44, 1-142.

Kunze, E., Dower, J.F., Beveridge, I., Dewey, R., Bartlett, K.P. (2006). Observations of biologically generated turbulence in a coastal inlet. Science 22, 1768-1770.

Lamb, J., Peterson, W. (2005). Ecological zonation of zooplankton in the COAST study region off central Oregon in June and August 2001 with consideration of retention mechanisms. Journal of Geophysical Research 110, C10S15, doi:10.1029/2004JC002520.

Lawson, G.L., Weibe, P.H., Ashjian, C.J., Gallager, S.M., Davis, C.S., Warren, J.D. (2004). Acoustically-inferred zooplankton distribution in relation to hydrography west of the Antarctic peninsula. Deep-Sea Research Part II 51, 2041-2072.

Mackas, D.L., Galbraith, M.D. (2002). Zooplankton distribution and dynamics in a North pacific eddy of coastal origin: I. Transport and loss of continental margin species. Journal of Oceanography 58, 725-738.

McCullagh, P., Nelder, J.A. (1989). Generalized linear models, Chapman & Hall/CRC.

Miksis-Olds, J.L., Nystuen, J.A., Parks, S.E., 2010. Detecting marine mammals with an adaptive sub-sampling recorder in the Bering Sea. Journal of Applied Acoustics 71, 1087-1092.

Miksis-Olds, JL, Parks, SE (2011). Seasonal trends in acoustic detection of ribbon seals (*Histriophoca fasciata*) in the Bering Sea. Aquatic Mammals 37: 464-471.

Miksis-Olds, JL, Stabeno, PJ, Napp, JM, Pinchuk, A, Nystuen, JA, Warren, JD, Denes, SL (accepted with revision) Ecosystem response to a temporary sea ice retreat in the Bering Sea. Progress in Oceanography.

Niebauer, H.J., Bond, N.A., Yakunin, L.P., Plotnikov, V.V. (1999). An update on the climatology and sea ice of the Bering Sea. In: Loughlin, T., Ohtani, K. (Eds.), Dynamics of the Bering Sea. University of Alaska Sea Grant, Fairbanks, AK, pp29-59.

R Development Core Team (2011). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Risch, D., Clark, C., Corkeron, P., Elepfandt, A., Kovacs, K., Lydersen, C., Stirling, I., Van Parijs, S. (2007). Vocalizations of male bearded seals, *Erignathus barbatus*: classification and geographical variation. Animal Behaviour 73(5): 747-762.

Schabetsberger, R., Brodeur, R.D., Ciannelli, L., Napp, J.M., Swartzman, G.L. (2000). Diel vertical migration and interaction of zooplankton and juvenile walleye pollock (*Theragra chalcogramma*) at a frontal region near the Pribilof Islands, Bering Sea. ICES J. Marine Science 57, 1283-1295.

Smith, P.E., Flerx, W., Hewitt, R.P. (1985). The CalCOFI vertical egg tow (CalVET) net. In: Lasker, R. (Ed.), An Egg Production Method for Estimating Spawning Biomass of Pelagic Fish: Application to the northern anchovy *Engraulis Mordax*. NOAA Technical Report NMFS 36, U.S. Department of Commerce, pp. 23-33.

Smith, S.L. (1991). Growth, development and distribution of the euphausiids *Thysanoessa raschi* (M. Sars) and *Thysanoessa inermis* (Kroeyer) in the southeastern Bering Sea. Polar Research 10, 461-478.

Smith, S. L., Vidal, J. (1986). Variations in the distribution, abundance, and development of copepods in the southeast Bering Sea in 1980 and 1981. Continental Shelf Research 5, 215–239.

Stabeno, P.J., Bond, N.A., Salo, S.A. (2007). On the recent warming of the southeastern Bering Sea shelf. Deep Sea Research Part II 54, 23–26.

Stabeno, P.J, Falry, E.V., Kachel, N.B., Moore, S., Mordy, C.W., Napp, J.M., Oveland, J.E., Pinchuk, A.I., Sigler, M.F. (2012). A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem. Deep- Sea Research II (available online February 21, 2012), doi:10.1016/j.dsr2.2012.02.019.

Stabeno, P.J., Hunt, G.L. Jr. (2002): Overview of the Inner Front and Southeast Bering Sea carrying capacity programs. Deep-Sea Research 49(26), 6157–6168.

Stabeno, P.J., Napp, J., Mordy, C., Whitledge, T. (2010). Factors influencing physical structure and lower trophic levels of the eastern Bering Sea shelf in 2005: Sea ice, tides and winds. Progress in Oceanography 85(3–4), 180–196.

Stanton, T.K. (1998). From acoustic scattering models of zooplankton to acoustic surveys of large regions. In: Proceedings of the IEEE Colloquium on Recent Advances in Sonar Applied to Biological Oceanography. London, UK.

Venables, W.N., Ripley, B.D. (2002). Modern applied statistics with S, Springer Verlag.

Wagner, T., Sweka, J.A. (2011). Evaluation of hypotheses for describing temporal trends in Atlantic salmon parr densities in Northeast US Rivers. North American Journal of Fisheries Management 31(2): 340-351.

Wang, M., Overland, JE. (2009). A sea ice free Arctic within 30 years? Geophysical Research Letters 36: L07502.

Warren J.D., Stanton, T.K., Wiebe, P.H., Seim, H.E. (2003). Inference of biological and physical parameters in an internal wave using multiple-frequency, acoustic-scattering data. ICES Journal of Marine Science 60, 1033-1046.

Watkins, J. L., Brierley, A.S. (2002). Verification of acoustic techniques used to identify and size Antarctic krill. ICES Journal of Marine Science 59, 1326-1336.

Watkins, W., Ray, G. (1977). Underwater sounds from ribbon seal, *Phoca (Histrophoca) fasciata*. Fishery Bulletin 75: 450-453.

Wood, S.N. (2006). Generalized additive models: an introduction with R, CRC Press.

Wood, S.N. (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society: Series B (Statistical Methodology).

Zuur, A.F. (2010). AED: Data files used in Mixed effects models and extensions in ecology with R. (2009). Zuur et al. (2009). R package version 1.0., Springer Verlag.

Zuur, A.F., Ieno, E.N. et al. (2009). Mixed effects models and extensions in ecology with R, Springer Verlag.

PUBLICATIONS

Nystuen, JA, Miksis-Olds, JL, Stabeno, PJ (in prep). Soundscapes under sea ice. Journal of the Acoustical Society of America.

Denes, SL, Miksis-Olds, JL, Mellinger, DK, Nystuen, JA. (submitted 6/2012). A comparison of marine mammal detections from two non-continuous autonomous acoustic recording systems: comparison of sub-sampled acoustic classifications. Special Issue on Methods for Marine Mammal Passive Acoustics, Journal of the Acoustical Society of America. [refereed]

Miksis-Olds, JL, Van Opzeeland, IC, Van Parijs, SM, Jones, J (submitted 3/2012). Pinniped sounds in the polar oceans. In Listening in the Ocean: New Discoveries and Insights on Marine Life From Autonomous Passive Acoustic Monitors (PAM). W.L. Au and M.O. Lammers, eds. Springer-Verlag.

Miksis-Olds, JL, Stabeno, PJ, Napp, JM, Pinchuk, A, Nystuen, JA, Warren, JD, Denes, SL. (accepted) Ecosystem response to a temporary sea ice retreat in the Bering Sea. Progress in Oceanography. [refereed]

Van Opzeeland, IC, Miksis-Olds, JL (2012). Acoustic ecology of pinnipeds in polar habitats. In Aquatic Animals: Biology, Habitats, and Threats. D.L. Eder, ed. Nova Science Publishers. Pp 1-52. [refereed]

Miksis-Olds, JL, Nystuen, JA, Parks, SE (2012). What does ecosystem acoustics reveal about marine mammals in the Bering Sea? In: Effects of Noise on Aquatic Life. A.N. Popper and A. Hawkins eds., Springer Science + Business Media, LLC. Pp 595-598.

Miksis-Olds, JL, Parks, SE (2011). Seasonal trends in acoustic detection of ribbon seals (*Histriophoca fasciata*) in the Bering Sea. Aquatic Mammals 37: 464-471. [refereed]

Miksis-Olds, JL, Nystuen, JA, Parks, SE. (2010). Detecting marine mammals with an adaptive sub-sampling recorder in the Bering Sea. Journal of Applied Acoustics 71: 1087-1092. DOI:10.1016/j.apacoust.2010.05.010. [refereed]

PRESENTATIONS

Denes, SL, Miksis-Olds, JL, Mellinger, DK, Nystuen, JA (2012). Comparison of daily detections from two passive acoustic systems. International Test and Evaluation Association (ITEA) Workshop. State College, PA, April 26.

Miksis-Olds, JL, Nystuen, JA (2012). The Passive Aquatic Listerner (PAL): an adaptive sampling passive acoustic recorder. Internation Test and Evaluation Association (ITEA) Workshop. State College, PA, April 26.

Miksis-Olds, JL, Denes, SL, Warren, JD (2012). A comparison of community structure from the southeastern and central Bering Sea shelf: insights gained from acoustic backscatter. Journal of the Acoustical Society of America 131: 3286. Hong Kong, China, 13-18 May, 2012.

Miksis-Olds, JL, Denes, SL, Nystuen, JA (2011). Ecosystem monitoring: providing the proper context for interpreting behavioral responses of marine mammals.” 4th Interngovernmetnal conference: The Effects of Sounds in the Ocean on Marine Mammals. Amsterdam, The Netherlands, 5-9 September.

Denes, SL, Miksis-Olds, JL, Nystuen, JA, Mellinger, DK (2011) A comparison of marine mammal detections from co-located sub-sampling passive acoustic monitors. Fifth International Workshop on Detection, Classification, Localization, and Density Estimation of Marine Mammals using Passive Acoustics, Mt. Hood, OR, 21-25 August.

Miksis-Olds, JL, Parks, SE (2011). Ribbon seal (*Phoca Histriophoca fasciata*) vocalizations in the Bering Sea. Acoustic Communication by Animals, Third International Symposium, Ithaca, NY, 1-5 August.

Miksis-Olds, JL, Warren, JD (2011). Characterizing biological scatter before, during, and after a temporary ice retreat in the Bering Sea. Journal of the Acoustical Society of America 129: 2401.

Miksis-Olds, JL, Nystuen, JA (2010). Factors influencing biodiversity and marine mammal habitat use in the Bering Sea. Journal of the Acoustical Society of America 127: 1758.

Miksis-Olds, JL, Nystuen, JA, Parks, SE (2010). What does ecosystem acoustics reveal about marine mammals in the Bering Sea? The Second International Conference:The Effects of Noise on Aquatic Life. Cork, Ireland. August 16-20.

Nystuen, JA, Miksis-Olds, JL (2010). Soundscapes under sea ice:Can we listen for open water? European Conference on Underwater Acoustics. Istanbul, Turkey. July 5-9.

Nystuen, JA, Miksis-Olds, JL (2010). Soundscapes under sea ice:Can we listen for open water? Acoustical Society of America, Baltimore, MD. April 19-23.

Miksis-Olds, JL, Nystuen, JA (2010). Acoustic tracking of upper trophic level dynamics in the Bering Sea. 2101 Ocean Sciences Meeting. Portland, OR. February 22-26.

Miksis-Olds, JL, Parks, SE, Nystuen, JA (2009). Understanding the relationship between marine mammals and their environment in the Bering Sea. Journal of the Acoustical Society of America 126: 2271.

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To: James E. Eckman, ONR 322
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From: Jeffrey Nystuen

Subj: ONR Grant N00014-08-1-0394, "Cumulative and Synergistic Effects of Physical, Biological and Acoustic Signals on Marine Mammal Habitat Use"

Encl: (1) SF298 for "Cumulative and Synergistic Effects of Physical, Biological and Acoustic Signals on Marine Mammal Habitat Use"
(2) Final Report for "Cumulative and Synergistic Effects of Physical, Biological and Acoustic Signals on Marine Mammal Habitat Use"

Please see the enclosures listed above, they constitute the final deliverables for the subject grant, "Cumulative and Synergistic Effects of Physical, Biological and Acoustic Signals on Marine Mammal Habitat Use". The work done under ONR Grant N00014-08-1-0394 was performed in support of ONR Grant N00014-08-1-0391 and the results were included in the final report for ONR Grant N00014-08-1-0391. Please accept enclosure (2) as the final report for the work performed under ONR Grant N00014-08-1-0394

Jeffrey Nystuen

cc: Grant & Contract Administrator, APL-UW
Office of Sponsored Programs, UW
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14. ABSTRACT
The long-term goal of this research effort was to enhance the understanding of how variability in physical, biological, and acoustic signals impact marine mammal prey and resulting marine mammal habitat use. This is especially critical in areas like the Bering Sea where global climate change can lead to rapid changes of the entire ecosystem. Synoptic measurements of marine mammal vocal presence, prey concentrations, physical oceanographic processes, and sound levels were made to better understand the relationship between environmental sound levels, ice cover and zooplankton community structure in different regions of the Bering Sea. These combined datasets provide information for predicting upper-level trophic dynamics, including marine mammal distribution and range, as sub-Arctic conditions continue to change. Baseline measurements are playing an important role in mitigation efforts and environmental assessments as commercial, recreation, and military activity increase in the region.

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